

# EFFECTIVENESS OF THE SHUTTLE ORBITER PAYLOAD BAY LINER AS A BARRIER TO MOLECULAR CONTAMINATION FROM HYDRAULIC FLUIDS

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## 1.0 INTRODUCTION

Recent investigations have identified potential source locations of contamination on the Shuttle Orbiter during on-orbit operations.<sup>1</sup> These sources include outgassing, offgassing, flash evaporator effluents, vernier control system, cabin atmosphere leakage and return flux. The payload bay of the Shuttle Orbiter is designed to contain numerous experiments that are expected to be extremely sensitive to even slight amounts of molecular contamination. Although the effects of molecular contamination vary somewhat for different molecular species, high molecular-weight components such as oils and hydraulic fluids can result in significant impairment of operation or degradation of experiment performance. This is particularly true in the case of experiments utilizing optical surfaces where a single monolayer of a contaminant could compromise the experiment objectives.<sup>2,3</sup>

One method of controlling contamination in the payload bay is the Shuttle Orbiter payload bay liner. For those specific payloads which are highly sensitive to contamination, the lower half of the Shuttle Orbiter payload bay inboard cavity will have a liner consisting of a teflon-coated Beta glass. This liner was designed to prevent particulate contamination generated in the mid-fuselage section from entering the payload bay.

Incorporated into this payload bay liner is approximately 6-1/2 ft<sup>2</sup> of stainless-steel filter material. This filter material will be installed in four ports on each side of the payload bay liner to permit gas exchanges

1. Rantanen, R. O.; Strange Jensen, D. A., Orbiter/Payload Contamination Control Assessment Support, Final Report

2. Richmond, Robert G. and H. N. Harmon, "An Instrument for Real-Time Detection of Contamination in Space Environmental Test Chambers"

3. Richmond, Robert G. and J. D. Hayes, "Development of Techniques for Advanced Optical Contamination Measurement with Internal Reflectance Spectroscopy,"

between the lower mid-fuselage area and the payload bay area. Air-flow patterns between these two areas could cause significant pressure differences across the liner due to repressurization/depressurization rate changes. This filter material, rated at 35 microns, is a twilled, double-dutch-weave (TDDW) pattern which forces the gas flow to change directions twice in passing through the filter.

In the Shuttle Orbiter configuration, hydraulic fluid systems are used to provide the power to actuate devices such as the elevons, main engine gimbal and control systems, landing gear, brakes, and steering mechanisms. The Shuttle Orbiter hydraulic subsystem is shown in figure 1. This power is derived from three, independent, hydraulic pumps, each driven by its own hydrazine-fueled auxiliary-power unit and cooled by its own water boiler. During on-orbit conditions these devices are not in operation, and the hydraulic fluid is kept warm by heat from the freon loop. The hydraulic pumps are located on the aft bulkhead of the Orbiter. Numerous fluid lines for these pumps are routed beneath the payload bay. Should leaks occur in these hydraulic fluid lines, hydraulic fluid could (1) saturate the payload bay liner and be emitted into the payload bay; and/or (2) transmit through the filter material where it could condense on sensitive payload experiments within the Orbiter's bay producing deleterious effects.

Recent investigations have been conducted to determine the effectiveness of the payload bay liner and filter material to serve as barriers to hydraulic fluids if spills or leaks occur in the hydraulic fluid lines. The specific objectives of these studies were as follows:

(1) Measure the transmission rate of the hydraulic fluid through representative samples of the payload bay liner and filter material. The hydraulic fluid used in this experiment is manufactured per specification MIL-H-83282A and consists of a blend of several different fluids. The average molecular weight is 421. Its specific heat and vapor pressure at 37.7°C are 0.50 BTU/LBM°F and 0.6 torr, respectively.

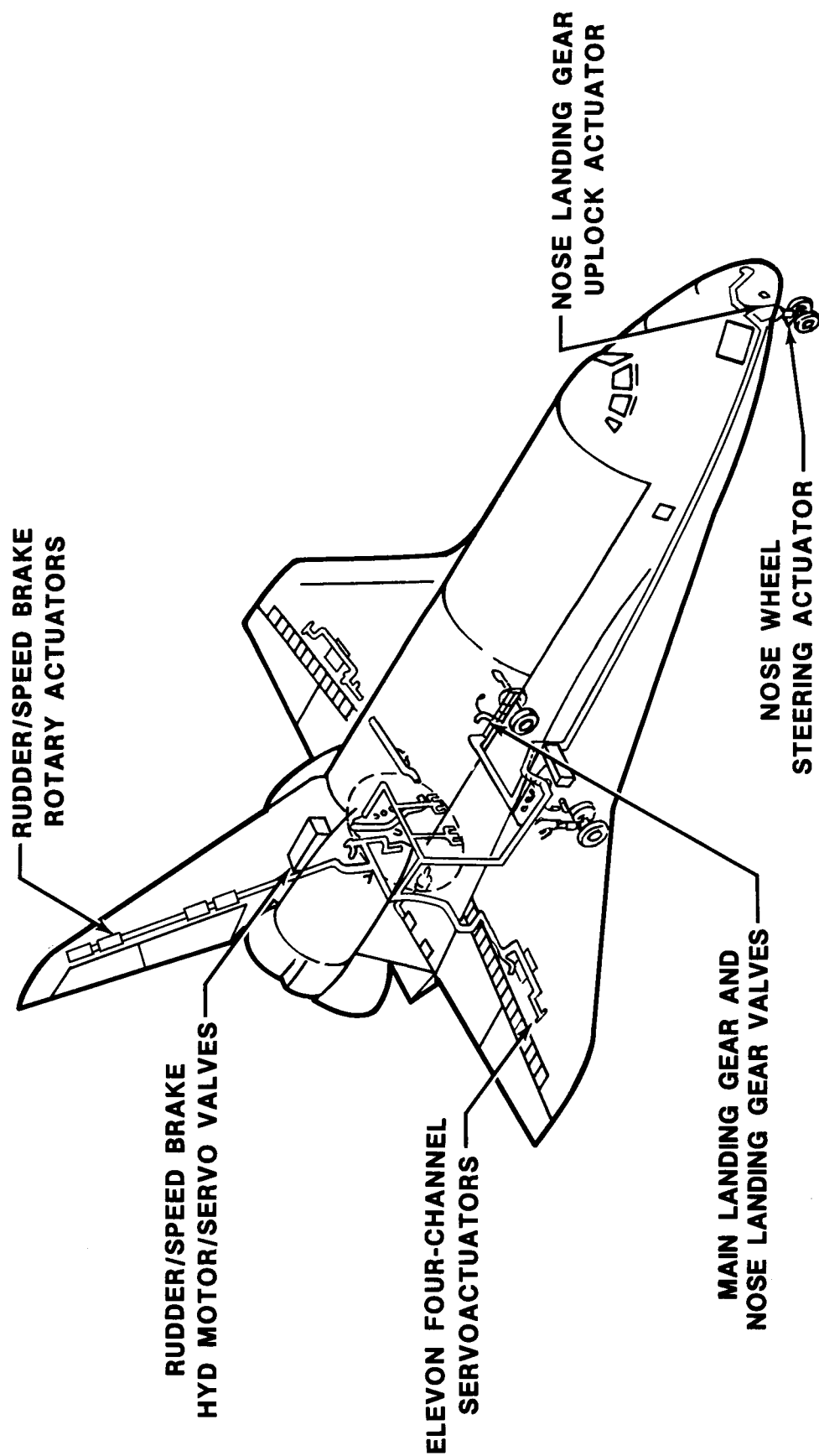


FIGURE 1.- SHUTTLE ORBITER HYDRAULIC SUBSYSTEM.

(2) Measure the relative condensation coefficient for the hydraulic fluid. The condensation coefficient is a dimensionless number that represents the ratio between the rate at which molecules actually condense on a surface and the rate at which they strike the surface.<sup>4</sup>

(3) Measure desorption rates for the hydraulic oil from contamination sensors. Since the hydraulic fluid is made of a combination of components, these components may condense at different collecting surface temperatures. Desorption rate measurements were performed to determine at what temperatures the condensed products would desorb from the quartz crystal microbalance.

## 2.0 EXPERIMENTAL APPROACH

The approach to this series of experiments was simple and straightforward - to simulate a hydraulic fluid leak and measure its transmission rate through single layers of the subject materials. To better understand the mechanisms of the molecule - surface interactions, and to assist in math modeling of the bay molecular contamination environment, the molecular condensation coefficient, and mass desorption rates were measured.

Since molecular contamination stemming from Shuttle Orbiter hydraulic fluid lines are considered leaks, a "molecular generator" to simulate an oil leak was designed and fabricated. Although we have designed and used molecular beam generators,<sup>5,6</sup> the use of a broader molecular source would more closely simulate an actual spill or leak. Total mass loss data of the oil (Bray Oil Co. #83282) at room temperature, 37.7°C, and 65°C at  $10^{-6}$  torr suggests that mass flux rates from even small samples would

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4. Dushman, S. (ed.), Scientific Foundations of Vacuum Techniques

5. Richmond, R. G., "Molecular Beam Generator"

6. Nuss, H. E., "Molecular Contamination Studies by Interaction of a Molecular Beam with a Platinum Surface"

exceed  $1 \times 10^{-8}$  gm/cm<sup>2</sup>.sec. These rates are measurable with the mass flux sensor (a thermoelectrically-cooled quartz crystal microbalance, TQCM) but cause some inconvenience because of saturation effects.<sup>7,8</sup> An incident mass flux rates of  $1 \times 10^{-9}$  gm/cm<sup>2</sup>.sec. or less would be ideal in terms of TQCM saturation effects and still maintain reasonably good measurement statistics.

### 3.0 EXPERIMENT CONFIGURATION

The requirements discussed above led to the configuration shown schematically in figure 2. The experimental series was conducted in a small space environment simulation chamber. The dimensions of the chamber are 1.1 m diameter and 1.4 m long; its vacuum system consists of a mechanical roughing system and two 4100-liter/sec. oil diffusion pumps with liquid-nitrogen-cooled baffles to reduce backstreaming of hot oil molecules into the test region. A liquid-nitrogen-cooled shroud installed within the chamber serves as a heat sink and cryogenically pumps condensable gases such as carbon dioxide and water vapor. Other main elements, viz. the molecular generator, the samples, and the TQCM and data system are described below.

#### 3.1 Molecular Generator

The molecular generator consisted of standard, off-the-shelf vacuum system components. The oil reservoir was simply a small 1.0" quartz viewport mated to a 2-3/4" vacuum flange. Two copper-constantan thermocouples, a small 50 watt thin-film heater and fiber glass tape insulation were used to measure and control oil temperature. The remainder of the system were four "drift tubes" 1.5" diameter with mating 2-3/4" vacuum flanges and a right-angle valve. Wrap-around heaters were used on all drift tubes and valve and maintained at least 30°C higher temperature than the oil to prevent condensation on the walls of the molecular generator.

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7. Visentine, J. T., R. G. Richmond, and R. M. Kelso, "Experiment to Measure Molecular Outgassing Rates from Shuttle Orbiter Flexible Reusable Surface Insulation (FRSI)"

8. Dillow, C. F., T. H. Allen, R. M. F. Linford, and Robert G. Richmond, "A System for the Study of Molecular Contamination"

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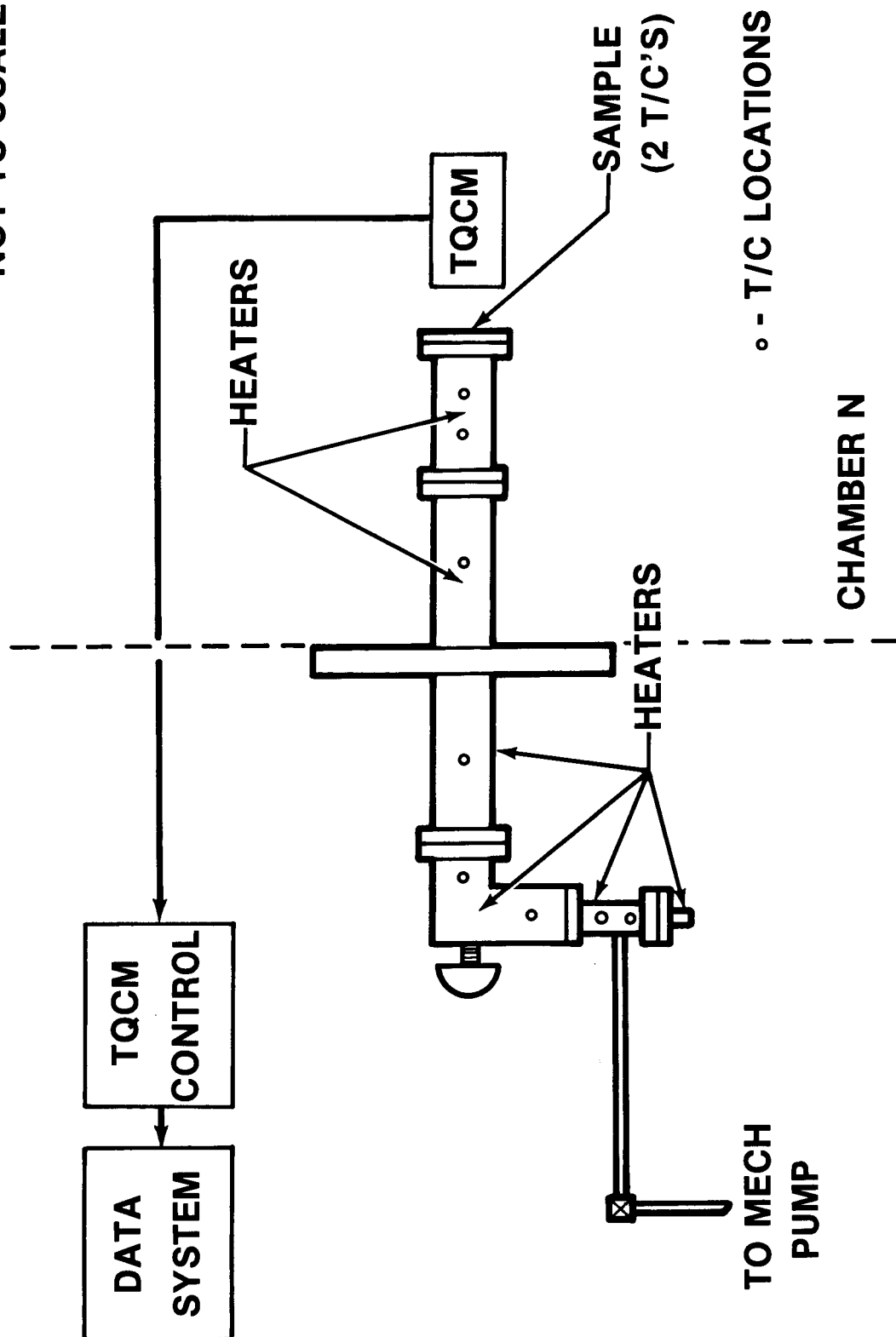


FIGURE 2.- EXPERIMENT CONFIGURATION.

### 3.2 The Samples

Two types of single-layer materials were evaluated: (1) a teflon-coated Beta glass cloth, and (2) a twilled, double-dutch-weave, TDDW stainless-steel filter. The teflon-coated Beta glass cloth, Dodge Industries, X-389-7, is the same 8 oz/yd<sup>2</sup> material used in the manufacture of space suits since the Apollo program. The samples are shown in figure 3.

The hydraulic fluid used in these experiments is Bray Oil Company No. 83282, manufactured per specification MIL-H-83282A and consists of a blend of several different fluids. The average molecular weight is 421.

### 3.3 Quartz Crystal Microbalance

The sensing element for this series of experiments was the TQCM. The TQCM consists of a sensor, heat sink, and electronics unit and is designed to operate in a space environment. The sensor consists of two 10-MHz piezoelectric quartz crystals, which are thermally controlled with a two-stage thermoelectric device. A precision platinum resistance thermometer is used to measure crystal temperature. The front crystal (sensing crystal) is located behind a window in a sensor cover. The second crystal (reference crystal) is situated directly behind the sensing crystal, which shields it from the molecular sources in the external environment. The heat sink is used to dissipate heat removed from the thermoelectric device when the crystals are cooled. The electronics unit generates voltages that drive the crystals to produce an audio beat frequency signal from which the condensing molecular flux rates are derived.

The TQCM operates on the principle that the quantity of mass accumulated on the sensing crystal, i.e. the incident molecular flux less the evaporating flux, is directly proportional to the changes in beat frequency produced by the electronics unit. The time rate of change of the beat frequency provides a measurement of the molecular flux as mass condenses on the sensing crystal. The sensitivity for the TQCM is typically  $3.5 \times 10^{-9}$  gm/cm<sup>2</sup>-Hz, and when it is used with a data system capable of resolving frequency changes as small as 0.1 Hz, mass loadings as small as  $3 \times 10^{-10}$  and repro-

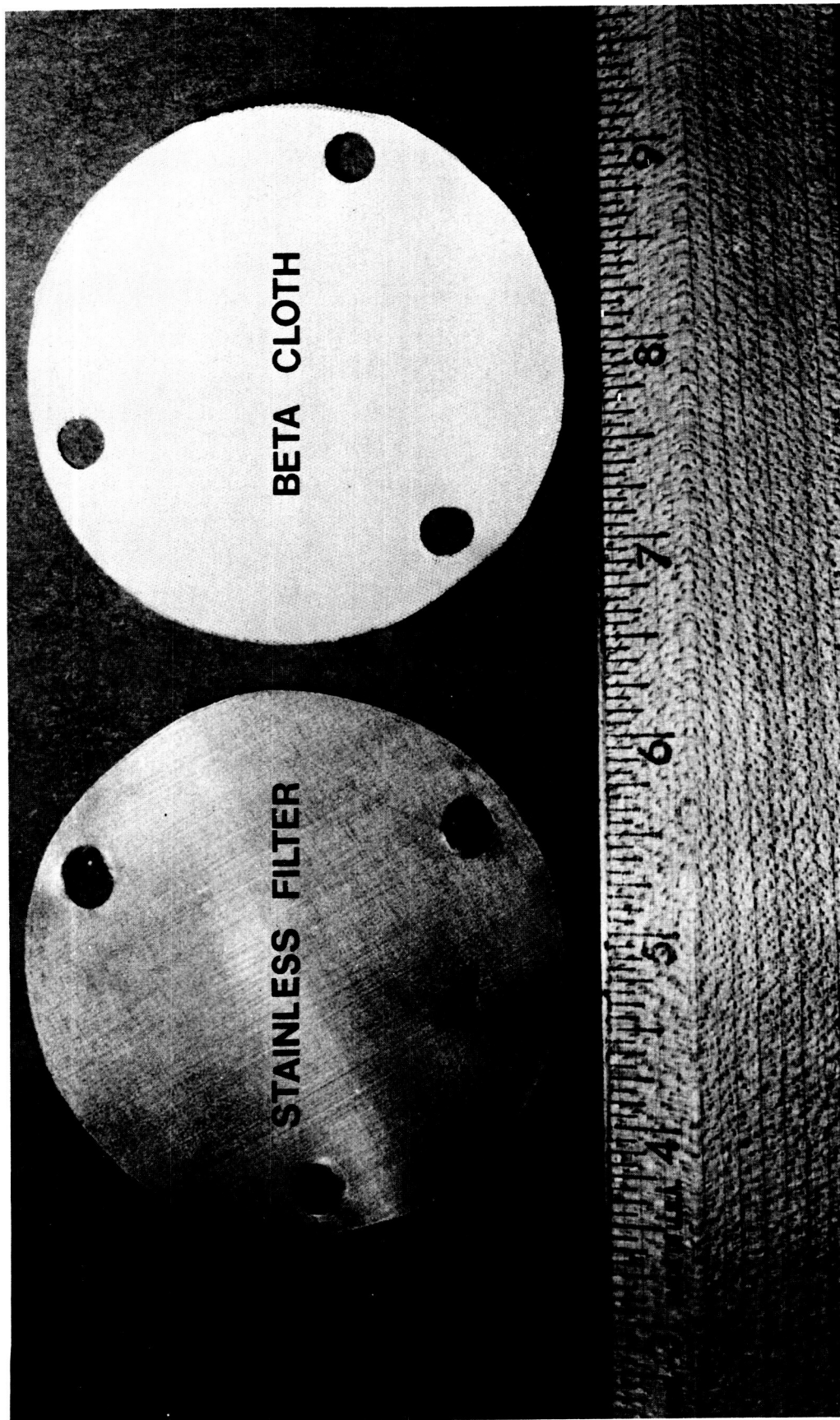


FIGURE 3.- SAMPLES OF PAYLOAD BAY LINER AND  
STAINLESS STEEL FILTER CLOTH.

ducible flux rates as low as  $7 \times 10^{-12}$  g/cm<sup>2</sup>.sec. have been detected.<sup>7</sup>  
A diagram of the TQCM is shown in figure 4.

Data system requirements for this series of experiments were straightforward although they represent state-of-the-art in quartz crystal microbalance measurements. Review of currently available instrumentation and techniques has shown few with any potential to measure such small frequency changes (averages of  $2 \times 10^{-3}$  Hz/sec.). As a result, a data system has been designed specifically for this type of application and includes the following general capabilities: 1) accuracy of one part in  $10^5$ , 2) selectable integration times, 3) selectable interval times, and 4) automatic mode of data recording. The details of this data system have been described elsewhere<sup>9</sup> and will not be included here.

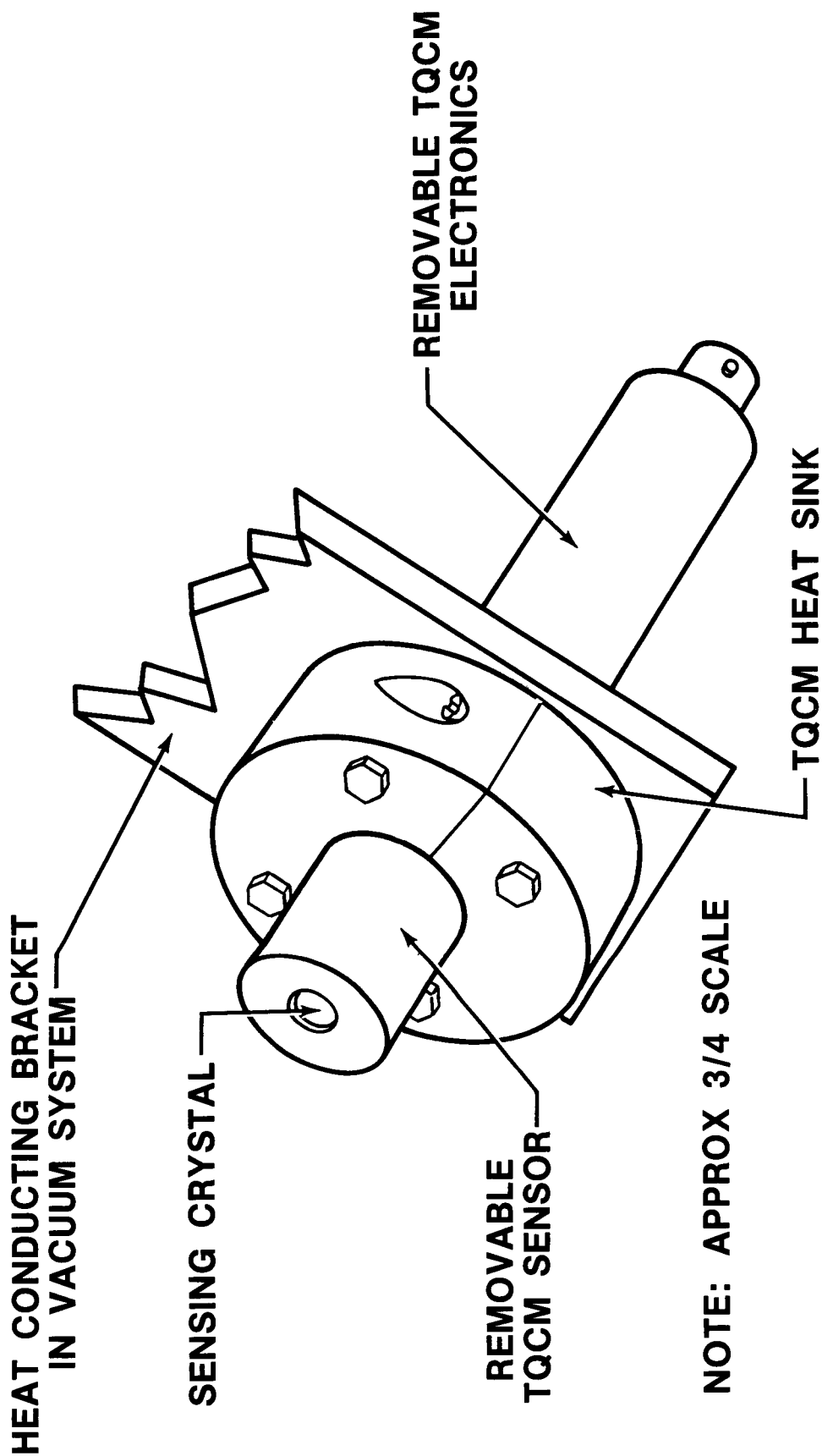
#### 4.0 EXPERIMENTAL PROCEDURE

The vacuum chamber was pumped to the  $10^{-6}$  torr range with the liquid nitrogen coldwall fully operational. The molecular generator was heated (oil to 65°C, drift tubing to 95°C) but was valved off from the main chamber. The TQCM, mounted on a rotational feedthrough, was adjusted to the proper temperature and rotated out of the beam to measure any background contamination. The molecular generator was rough pumped a few minutes to eliminate the bulk of air present. The roughing valve was closed and the molecular generator was opened to the main chamber. The TQCM was rotated into the beam for measurements every half hour. Rotation of the TQCM out of the beam prevented saturation of the sensor crystal. This general approach, both with and without samples installed, was used throughout this experiment series.

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7. Visentine, J. T., R. G. Richmond, and R. M. Kelso, "Experiment to Measure Molecular Outgassing Rates from Shuttle Orbiter Flexible Reusable Surface Insulation (FRSI)"

9. Richmond, R. G., "Instrumentation for Measuring Low-Level Currents/Voltages"



TQCM SENSITIVITY:  $4 \times 10^{-9} \text{ g/cm}^2 \cdot \text{Hz}$

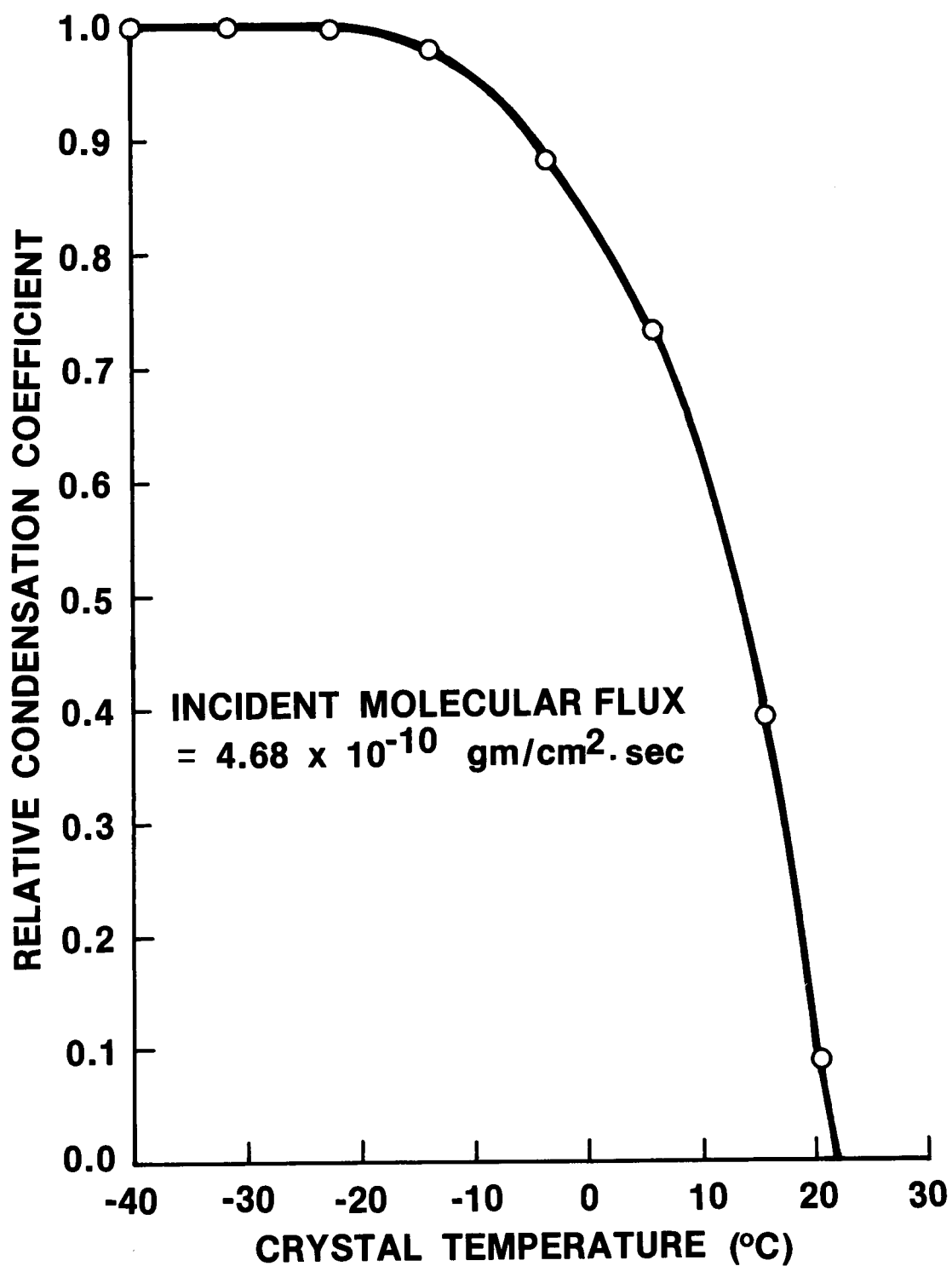
FIGURE 4.- THERMOELECTRICALLY-COOLED  
QUARTZ CRYSTAL MICROBALANCE (TQCM).

## 5.0 EXPERIMENTAL RESULTS AND DISCUSSION

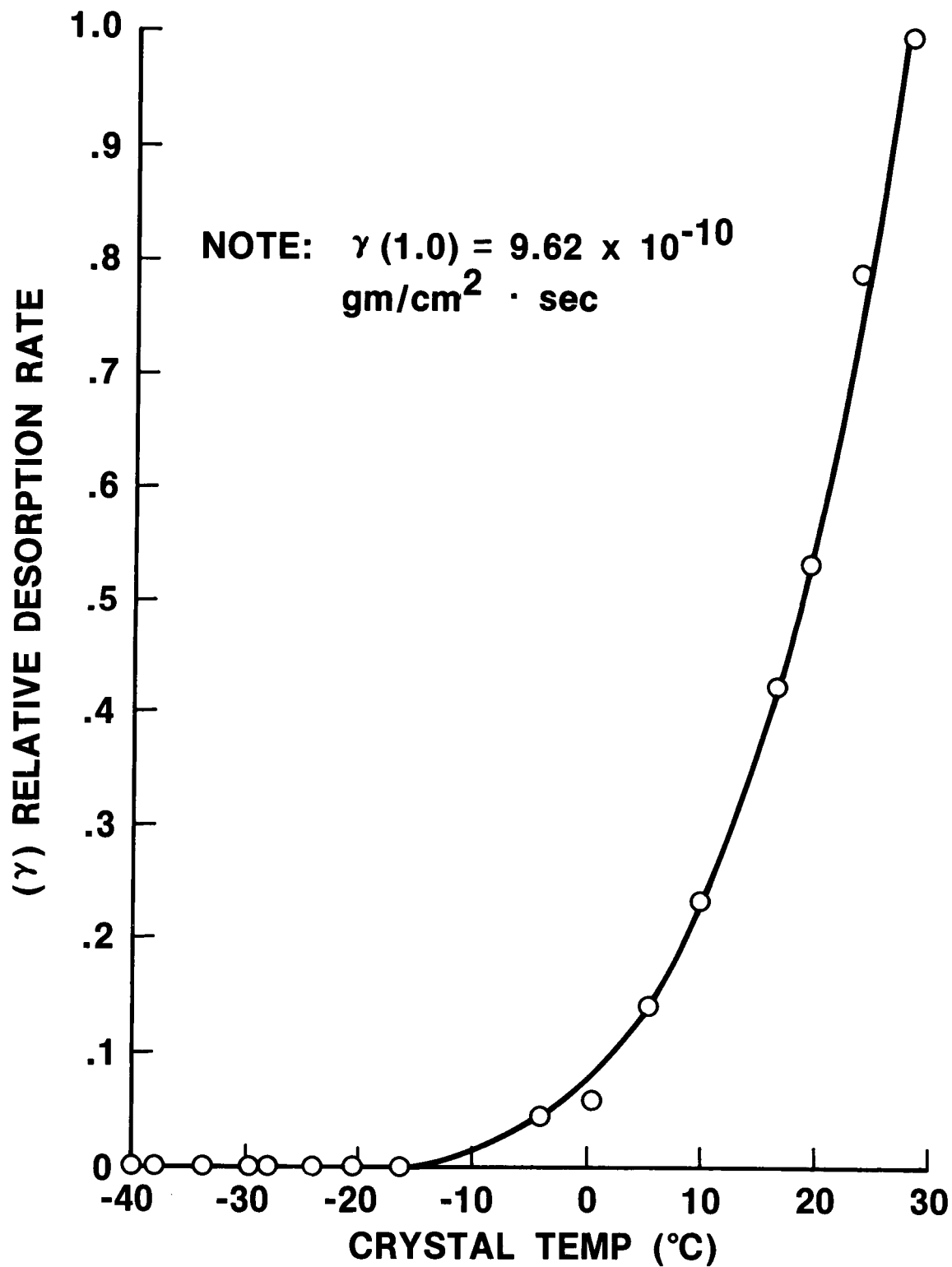
The success of the experimental approach depended upon the ability of the molecular generator to reproduce the same molecular flux as a function of time if the oil amount, oil temperature, and vacuum environment conditions were carefully controlled. Earlier attempts to control the molecular flux solely with the pressure within the molecular generator were unsuccessful since the pressure was too low to measure accurately with a capacitance manometer and too unstable with an ionization gage (sensitivity varied). Four separate twenty-hour runs, made with the oil temperature  $65 \pm 1.5^\circ\text{C}$ , indicate a flux reproducible to within about  $\pm 6\%$  overall. Two cubic centimeters of oil,  $1.713 \pm 0.016$  grams, were used for each run. Excess oil from previous runs was discarded and the oil reservoir thoroughly cleaned.

The next step was to measure the condensation coefficient for the oil (no sample installed). A low, stable, flux of about  $5 \times 10^{-10} \text{ g/cm}^2\cdot\text{sec.}$  was produced and the crystal temperature was incrementally lowered from  $+30^\circ\text{C}$  to  $-40^\circ\text{C}$ . These data are shown in figure 5. It is apparent from these data that the hydraulic fluid has a unity condensation coefficient below about  $-25^\circ\text{C}$ , a value typical of heavy hydrocarbons. The experiment was repeated after rapid desorbing of the condensed contaminant. The data shown in figure 5 were reproducible to better than  $\pm 3\%$ . This can be attributed to the extremely stable incident molecular flux and the integration method of data acquisition. Since the crystal of the TQCM represents a "near perfect" substrate for condensation coefficient studies, it should be pointed out that some uncertainties must be expected when applying these values to other surfaces, e.g. Beta cloth and screen material. Condensation is a complex phenomenon. Molecular accommodation is dependent on many variables including molecular species, molecular energy, angle of incidence, as well as substrate temperature, material, and finish. Data shown in figure 5, however, can probably be used as rough approximation for other materials and finishes if the uncertainties are understood and acceptable.

A reverse of the above procedure yielded the data shown in figure 6, the relative desorption rate of the hydraulic fluid from the crystal. The



**FIGURE 5.- RELATIVE CONDENSATION COEFFICIENT  
VS TQCM CRYSTAL TEMPERATURE.**

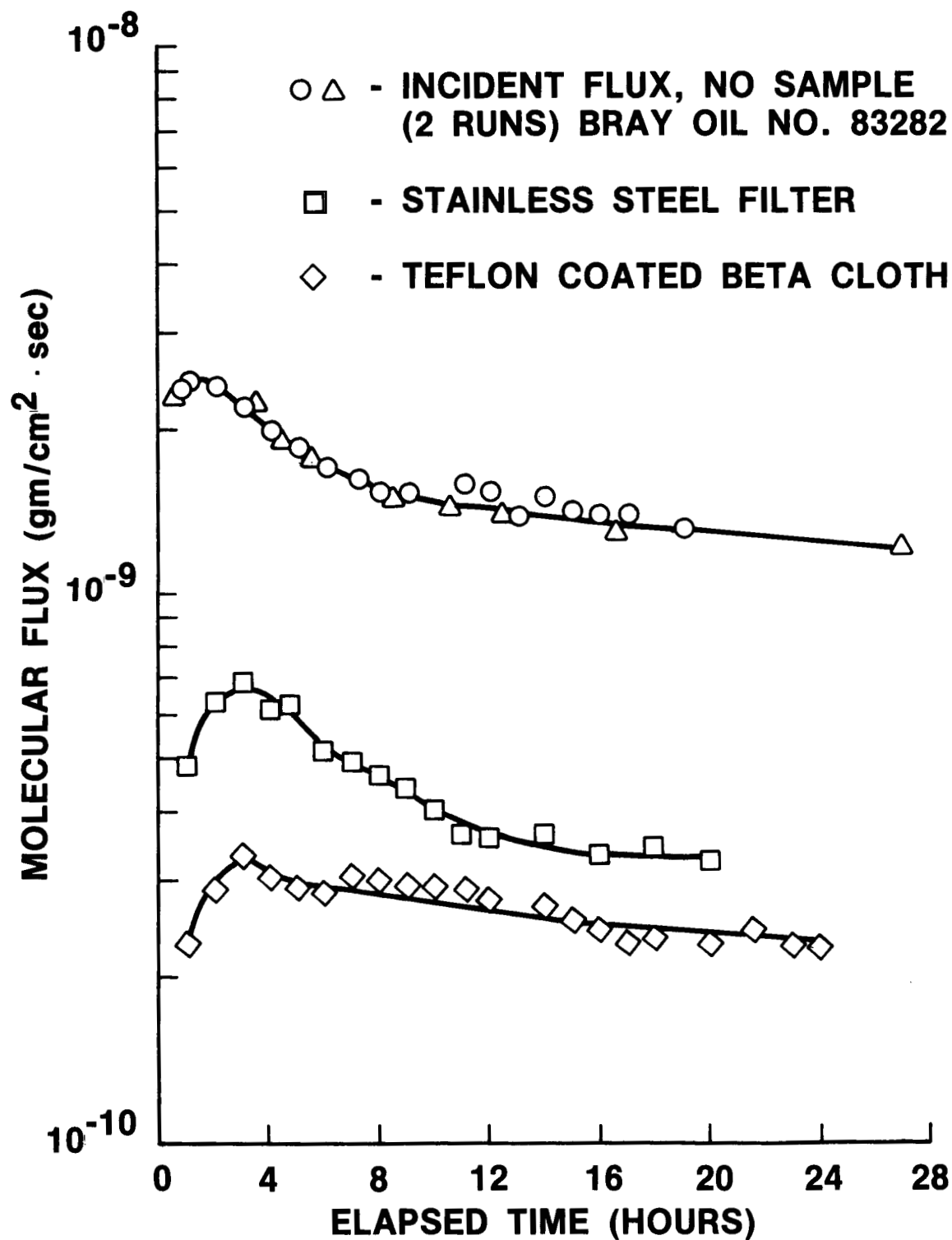


**FIGURE 6.- RELATIVE DESORPTION RATE VS  
TQCM CRYSTAL TEMPERATURE.**

desorption rates shown in figure 6 are not linear but increase exponentially with microbalance temperature, results typical of heavy (high molecular mass) compounds. It was stated earlier that the accumulated mass flux as measured by a quartz crystal microbalance is equal to the incident molecular flux less the evaporated flux. This experiment verified that the evaporated flux is negligible for microbalance temperatures of  $-25^{\circ}\text{C}$  or less. Repeat of this experiment showed reproducibility of the measured values to average  $\pm 8.7\%$ , a value somewhat poorer than that measured for the condensation coefficient study. This can be attributed to the fact that adsorbed molecules can migrate over the surface, giving rise to collisions with other molecules, and aggregates of adsorbed molecules develop. Aggregates are bound to each other by the condensation energy. Uncertainties then can be caused by molecular "island" clustering on the substrate.

The molecular generator was operated sans sample to verify the incident molecular flux, and the samples were installed and the experiment repeated. Typical results of the transmission of the hydraulic oil through the screen material and the Beta cloth are shown as curves 2 and 3 of figure 7, respectively. As can easily be seen from figure 7, after 12 hours the rate of transmission of the hydraulic fluid is about 24.8% and 18.4% for the screen and Beta cloth, respectively. Both of these values represent a remarkable effectiveness in inhibiting fluid transmission considering the woven characteristics of these single-layer samples. In addition, it should be noted that, due to the nature of the experiment, none of the samples were operated at lower than room temperature  $25 \pm 3^{\circ}\text{C}$ , a temperature in which the condensation coefficient is near zero. This suggests that all fluid molecules follow line-of-sight or scattered trajectories through the sample, i.e., none "saturate" the cloth. It was noted that increasing the temperature of the sample to  $60^{\circ}\text{C}$  had no measurable effect in increasing the rate of transmitted molecular flux.

One of the more significant on-orbit conditions could not be simulated by our experiment geometry, viz. when the hydraulic fluid temperature is near its nominal value. These conditions occur after the payload bay doors are opened, and the hydraulic fluid is kept warm by circulating it



**FIGURE 7.- TYPICAL HYDRAULIC FLUID  
TRANSMISSION RATES THROUGH  
PAYLOAD BAY LINER MATERIALS.**

through heat exchangers to transfer heat from the freon loop. Hydraulic fluid temperatures and bay liner temperatures corresponding to this mission sequence are  $-1.1^{\circ}\text{C}$  and  $-60^{\circ}\text{C}$ , respectively. Lower fluid temperature will result in significantly lower incident molecular flux. In addition, the payload bay liner at  $-60^{\circ}\text{C}$  should condense any incident flux and prevent it from reaching the experiment areas. The data generated by the described experiment can be considered as worst-case simulation.

## 6.0 CONCLUSIONS

An experiment has been conducted to measure the rate of transmission of Shuttle Orbiter hydraulic fluid through two single-layer sample materials for one fluid temperature. These materials demonstrate remarkable effectiveness in inhibiting transmission of the hydraulic fluid considering their woven characteristics.

Although one of the more significant Shuttle Orbiter on-orbit conditions was not simulated it was shown that the conducted experiment could be considered as a worst case example.

The effective condensation coefficient and the desorption rate of the Shuttle Orbiter hydraulic fluid has been measured, utilizing a sensitive thermoelectrically-cooled quartz crystal microbalance, TQCM, and unique data acquisition techniques. The values determined by this series of experiments are basically consistent with those measured for other heavy hydrocarbons.

In addition, it has been conclusively demonstrated that a simple molecular generator, designed and constructed from standard, off-the-shelf vacuum system components, can effectively and consistently produce molecular fluxes simulating an oil leak in a space-simulated environment.

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